Management Measure 2
Watershed Assessment

A. Management Measure

Develop and implement a watershed assessment program to

- Characterize watershed conditions.
- Establish a set of watershed indicators.

B. Management Measure Description and Selection

1. Description

Watershed assessment and monitoring are tools used to characterize water quality and to identify trends in water quality over time (USEPA, 1998c). This management measure describes methods that can be used to determine the health of waterbodies using watershed indicators that measure physical, chemical, and biological conditions.

2. Management Measure Selection

In 1999 states developed Unified Watershed Assessments that draw on the full range of information to

- Assess the health of watersheds and identify watersheds in need of restoration (i.e., watersheds that do not now meet clean water and other natural resource goals).
- Identify watersheds that need preventive action to sustain water quality using ongoing state, tribal, and federal programs. Identify pristine or sensitive watersheds on federal lands that need an extra measure of protection.

State pollution control agencies and Indian tribes typically are responsible for watershed assessment and monitoring activities. States, interstate commissions, and tribes monitor water quality and identify waters and watersheds not meeting clean water goals through various programs, including the following:

- Water quality reporting program, established under CWA section 305(b), which mandates the collection of water quality information and reporting on the condition of waters every 2 years.

- 303(d) program, established under CWA section 303(d), which mandates the use of monitoring and other water quality information to develop lists of waters not meeting water quality standards.

- Nonpoint Source Program, established under CWA section 319, which involves identifying waterbodies that are impaired by nonpoint sources.

- Source Water Protection Program, established under the Safe Drinking Water Act, which involves assessments of drinking water sources that form a basis for actions to protect such sources.

- State Revolving Fund (SRF) Program, which involves developing and prioritizing clean water projects.

- Federal Emergency Management Agency's National Flood Insurance Program, which involves conducting floodplain studies and developing mitigation plans.

- Marine pollution control programs, which include identifying coastal water quality problem areas as part of efforts to reduce polluted runoff to coastal waters.

Case Study: Pennsylvania Watershed Assessment Objectives

The Commonwealth of Pennsylvania, in Act 167, requires that watershed assessments consider the following objectives (Pennsylvania DEP, 1999):

- Implement nonpoint source pollutant removal methodologies.
- Maintain ground water recharge.
- Reduce channel erosion.
- Manage overbank flood events.
- Manage extreme flood events.

The state established four subtasks to achieve these objectives:

- Determine the water quality design storm.
- Determine the runoff capture design storm (recharge/retention).
- Establish streambank erosion requirements.
- Establish overbank/extreme event requirements (release rates).

To accomplish these subtasks, the state developed a process to identify the need for data and to obtain committee input to define a schedule for data analysis and interpretation that will ultimately lead to the development of standards for streambank erosion, infiltration, water quality, overbank flooding, and extreme storm events. The assessment fits into a larger framework for integrated watershed resource management, which includes the following steps:

- Watershed assessment/prioritization.
- Watershed evaluation.
- Restoration/protection plan development.
- Financial resources secured.
- Restoration/protection plan implementation.
- Results compared to goals.

- Wetlands Program, which involves developing assessments of wetland areas that need special attention or protection.

A monitoring program is important for effective watershed management because it provides a basis for decisions and actions and allows managers to continually reassess progress and redefine goals and priorities. Monitoring enables water quality managers to identify existing or emerging water quality problems. Monitoring also facilitates responses to emergencies such as spills and floods and helps water quality managers target specific pollution prevention or remediation programs to address these problems. Assessment and monitoring can be used to determine whether program goals, such as compliance with pollution regulations or implementation of

Planning for Watershed-Scale Monitoring of Freshwater Ecosystems

The Nature Conservancy (TNC, 2000) has developed a document that provides guidance for establishing freshwater ecosystem monitoring at the watershed or landscape scale, particularly for the adaptive management of freshwater biological diversity. Planning for Watershed-Scale Monitoring of Freshwater Ecosystems, which is pending publication, provides a step-by-step process with two sets of guidelines. The first set describes the process for assessing freshwater monitoring needs and includes the following nine steps:

1. Identify and prioritize the conservation questions in the site conservation plan and identify the conservation zone to which each pertains.
2. Identify the level of monitoring intensity needed to address each question and reach a useful answer.
3. For each question, determine which variables or indicators should be monitored.
4. Identify covariates for each of the variables or indicators identified in Step 3.
5. Determine a sampling schedule for each variable, indicator, and covariate.
6. Determine sampling locations for each variable, indicator, and covariate.
7. Determine sampling and measuring methods for each variable, indicator, and covariate.
8. Determine quality assurance and quality control procedures needed for each variable, indicator, and covariate.
9. Integrate the results of Steps 1 to 8 and identify and refine measurement suites.

The second set of guidelines describes the process for developing a monitoring action plan and includes the following four steps:

1. Identify the resources available to support a monitoring program and the major barriers to its implementation.
2. Evaluate the priority for and feasibility of monitoring each measurement suite based on the site's conservation priorities.
3. Identify the amount of short-term and long-term monitoring that can be accomplished.
4. Revise conservation priorities, monitoring needs, and fund-raising and partnership goals until the monitoring plan is feasible, fundable, and institutionally appropriate and meets the conservation needs.

These guidelines allow users to establish a monitoring program that will provide crucial information for guiding management decisions.

effective pollution control actions, are being met. Monitoring programs should be established based on indicators of human health and aquatic life. A large number of documents and case studies are available to use as resources (see Information Resources at the end of this chapter).

C. Management Practices

1. Characterize Watershed Conditions

a. Establish a reference condition

It is important to establish a reference condition that characterizes the relatively unimpaired condition of the waterbody. The reference condition establishes a basis for making comparisons between sites and is essential for detecting impairment. There are two types of reference conditions—site-specific and regional. Site-specific reference conditions are determined from one or more sites upstream from a point source discharge or from a paired watershed, which is a watershed similar in size and characteristics to the watershed of interest. Site-specific reference sites are advantageous because their habitat is often similar to that measured downstream of a discharge, which reduces complications in data interpretation arising from habitat differences. Also, impairments due to upstream influences from other point and nonpoint sources are already factored into the reference condition. However, site-specific reference sites lack broad study design and their capacity for extrapolation is limited. They also have limited variance estimates: because each site of concern typically is represented by one to three reference sites, the result could be an incorrect assessment if the upstream site has especially good or especially poor habitat or chemical quality. In addition, site-specific reference sites involve a substantial assessment effort when considered on a regional or statewide basis.

Regional reference conditions are established from a population of relatively unimpaired sites within a relatively homogeneous region and habitat type. An ecoregional framework based on land-surface form, soil, potential natural vegetation, and land use has been developed by Omerink (1987) to interpret spatial patterns in data (USEPA, 1999); these ecoregions can be used to help develop a reference condition for a relatively homogeneous region. Regional reference conditions are often preferable to site-specific conditions because they are more widely applicable, they produce a larger sample of unimpaired sites, and they allow more robust statistical comparisons.

b. Model pollutant sources and loads

Watershed managers can use models to estimate storm water pollutant loadings to receiving waterbodies. Modeling of pollutant loadings can help watershed managers target specific areas for nonpoint source control. More specifically, runoff models can accomplish one or more of the following:

- Simulate the generation and movement of water and pollutants from their point of origin to a place of treatment or disposal into receiving waters.

- Perform frequency analyses on water quality parameters to determine the return periods of concentrations or loads.

- Provide input for an analysis of receiving water quality.

- Determine the relative effects of pollution control options.

- Determine optimal locations and combinations of management practices.

- Provide input to cost-benefit analyses.

Selecting the model that is most appropriate to fulfill watershed management goals requires careful consideration of trade-offs with respect to level of detail, data requirements, cost, and accuracy. For example, a high level of detail requires a more complex model. Data requirements are also important: a complex model might require more data than one has or is willing to collect. Sometimes published data can be substituted for field-collected data. The advantage to using published data is that costly, labor-intensive fieldwork can be avoided. One problem associated with using published data, however, is that the measured watershed might not adequately represent the watershed of interest. A major data source is the USEPA National Urban Runoff Program (NURP) database, which contains concentration values measured for 30 cities (USEPA, 1983). Information that is generally required for models includes the following:

Quantity Parameters

- Rainfall information
- Catchment area
- Imperviousness
- Runoff coefficient

Quality Parameters

- Constant concentrations (event mean concentrations or EMCs)
- Constituent median and coefficient of variation (CV)
- Regression relationships
- Buildup and washoff parameters

Calibration/Verification Parameters

- Measured rainfall
- Measured runoff
- Water quality samples

Another consideration when choosing a model is its reputation. Watershed managers should become familiar with the model's concepts, assumptions, and limitations, as well as the experiences of other users. In choosing the most appropriate model, watershed managers should

- Use the simplest model that will satisfy the project's objectives.
- Use a model that is consistent with available data.

- Predict only the water quality parameters of interest.
- Make predictions over the broadest time scale that will satisfy the objectives.
- Become familiar with the characteristics and assumptions of the model.

Using pollutant loading models has pros and cons. Measured data are preferable to simulated data, especially when characterizing the magnitude of a pollution problem, because accurate concentration values are important. Models cannot substitute for good field-sampling programs, but they can be used to extrapolate and to augment field-sampling results.

To ensure quality results from a modeling effort, sensitivity analyses should be performed when uncertainty exists regarding data quality or model assumptions. Also, models should be calibrated and validated if possible using measured values (field monitoring). This process is labor-intensive and can add to the expense of the modeling effort, but it is worthwhile to ensure accuracy when making management decisions.

Watershed managers can choose from several different methodologies depending on the specific goals of the modeling effort, including

- *Constant concentration or published yield values*. This method involves calculating loads as the product of the proportion of land area in a particular land use and the published loading rates for that land use. A disadvantage is that the catchments from which the published values are derived are not likely to represent the catchment of interest. However, the calculations are very simple and easy to use for general loading assessments. Options include coupling constant concentrations with a hydrologic model so that loading will vary with flow or calculating a confidence interval for loading to determine the level of uncertainty that can be tolerated before conclusions change. This method might be robust enough to answer straightforward management questions despite assumptions.

- *Unit loads.* This method involves calculation of the mass of the pollutant of interest per area of watershed per unit of time. It is site-specific (demographic and hydrologic factors are important determinants) and is based on average runoff volume (not coupled to a hydrologic model). Also, loading rates are variable and difficult to extrapolate from one area to another. This is a relatively simple method that does not require a great deal of data collection. Published values can be used at the expense of some accuracy.

- *Simple empirical model*. Spreadsheet calculations combine precipitation data with a runoff coefficient and land-use-specific constant concentrations. This method easily simulates a mixture of land uses, allowing the study area to extend over a large area without compromising the quality of results. The model can quantify relative contributions from different land uses and can be expanded readily to incorporate more complex calculations. The hydrologic modeling is very simple, however, and the model does not necessarily work well for short-term predictions. Also, using published constant concentrations in the model introduces error; locally measured concentrations would greatly improve the model’s performance.

- *Statistical method.* The statistical method uses a derived, usually lognormal frequency distribution of estimated mean concentrations of pollutants. This method is useful for assessing frequency of exceedance of water quality standards, but it has weak hydrologic assumptions. The model can be coupled with stream flow, storage, and treatment data to improve accuracy and estimate the effects of management practices on water quality. Estimates can be improved by using measured EMC values rather than published ones. EMCs can vary widely because of seasonal and watershed land use variations and might require at least 1 year and often 2 years of field verification to be statistically significant.

- *Regression equations.* Regression equations are published equations from the U.S. Geological Survey (USGS) (Driver and Tasker, 1990) that relate loads and EMCs to catchment, demographic, and hydrologic characteristics. They usually incorporate total storm event loads and runoff flows or volumes. They require neither preliminary estimates of EMCs nor local monitoring data, and standard errors are provided for a measure of uncertainty. They are more or less accurate depending on the pollutant of interest and the level of precipitation (arid vs. humid). The equations predict only the mean rather than a frequency distribution of EMCs or loads, and they are subject to error when extrapolating to conditions that are different from those used to derive the equations. A related approach uses rating curves to relate pollutant loads or EMCs to flow rates or volumes, thereby allowing quantification of intrastorm variations in these measures.

- *Buildup and washoff.* Loading is determined by combining the buildup of pollutants during dry weather and washoff during rainfall events. This method quantifies intrastorm variations in pollutant loading and is good for comparing the relative effects of management practices. However, processes of sediment transport and erosion that are fundamental to this method are still poorly understood. Moreover, this method requires averaging the extent of pollutant buildup on heterogeneous urban surfaces. This averaging can result in erroneous predictions because actual values vary widely over relatively small areas. Assumptions include linear buildup and generic washoff coefficients that might or might not represent actual conditions. Estimates can be improved by using local monitoring data such as site-specific buildup and washoff estimates for model calibration.

- *Mechanistic models.* Mechanistic models contain hydrologic and water quality components and have mathematical algorithms to represent the mechanisms that generate and transport runoff and contaminants. They are the most comprehensive models in that they incorporate many variables to produce the best estimations of the numerous mechanisms that affect pollutant loading. However, they require substantial local data to set and verify parameters, and they demand both skill and commitment from staff. Users must ensure that the models are documented, supported, and proven through the experience of other users. There are several commercially available mechanistic models, including STORM by the U.S. Army Corps of Engineers and SWMM and HSPF by EPA. (See web references and resources below.)

Pollutant fractions or potency factors can be used for pollutants adsorbed to solids because these pollutants can be estimated as a proportion of the total suspended solids concentration or annual load. This method is most appropriate for metals and organics and can be combined with other models for a more accurate estimate of adsorbed pollutants.

The confounding factors for load estimation models are

- Inputs from atmospheric deposition (H_2SO_4, NO_3, etc.).
- Ground water inputs.
- Pervious surfaces that confound runoff estimates.
- Sediment transport and erosion.
- Point sources in the watershed (e.g., industrial and commercial sources and publicly owned treatment works).

All of these factors can be included in the surface runoff model at the expense of time and simplicity, but they can improve the accuracy of loading estimates. Before they are included, consideration should be given to the level of detail needed for the analysis.

c. Model receiving water quality

Receiving water quality models identify impacts from runoff inputs and help watershed managers determine whether receiving waters meet water quality standards. Usually computer models are used because of the complexity of calculations. Models are available for streams, lakes, reservoirs, estuaries, bays, and coastal segments. Most models couple both quantity (hydrodynamic) and quality parameters, but some consider these parameters separately. Other receiving water quality models include a surface runoff model that quantifies inputs to the receiving waters.

A useful water resource impact model is the Long-Term Hydrologic Impact Assessment (L-THIA), which was developed by Purdue University (2000) for land use planners to provide site-specific estimates of changes in runoff, recharge, and nonpoint source pollution resulting from past or proposed land use changes. The model uses regional climate data and user-provided location, land use, and soil group data for up to three different scenarios (past, present, and future). The results are in the form of tables, bar charts, and pie charts. The model is available at *danpatch.ecn.purdue.edu/~sprawl/LTHIA7*.

The best sources of information for receiving water quality models are either government agencies or product vendors. The following is a list of government agencies that can provide the information needed to choose the most appropriate model:

- USEPA Center for Exposure Assessment Modeling, Athens, Georgia.
- US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.
- US Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

- USGS, Reston, Virginia.

- National Oceanic and Atmospheric Administration (NOAA), Silver Spring, Maryland—estuaries and bays.

- Tennessee Valley Authority (TVA), Knoxville, Tennessee—rivers and reservoirs.

Additional guidance regarding load estimation and receiving water quality modeling is provided in *Compendium of Tools for Watershed Assessment and TMDL Development* (USEPA, 1997a), which supports the watershed approach by summarizing available techniques and models that assess and predict physical, chemical, and biological conditions in waterbodies. This document is intended to provide watershed managers and other users with information helpful for selecting models appropriate to their needs and resources. Specifically, it includes information on the following:

- A wide range of watershed-scale loading models.

- Field-scale loading models.

- Receiving water models, including eutrophication/water quality models, toxics models, and hydrodynamic models.

- Integrated modeling systems that, for example, link watershed-scale loading with receiving water processes.

- Ecological techniques and models that can be used to assess and/or predict the status of habitat, single species, or biological communities.

An additional modeling resource is *Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas*, which is a major nonpoint source model review effort published by EPA in 1991. It focuses on nonpoint source assessment procedures and modeling techniques for both urban and nonurban land areas (Donigian and Huber, 1991). The report provides detailed reviews of specific methodologies and models as well as overview discussions and model comparison tables. Simple procedures, such as regression and loading function approaches, are also described in the report, along with complex models like SWMM, HSPF, STORM, CREAMS/GLEAMS, SWRRB, AGNPS, and others. Brief case studies of modeling efforts are summarized, with emphasis on the use of nonpoint and comprehensive watershed models for watershed management activities. Other publications that can provide watershed managers with modeling information can be found at www.epa.gov/oiamount/tips/wq.htm (USEPA, 1998a).

d. Assess cumulative effects

A watershed assessment should include an evaluation of cumulative effects, which are combined effects of multiple activities over space or time. Such effects can be difficult to assess because a large number of resources can be affected and there are multiple pathways through which these effects can occur. Also, the appropriate spatial and temporal scales for the analysis usually are uncertain. Because many environmental assessments do not take cumulative effects into account, most likely because there is no explicit process for analyzing them, MacDonald (2000)

Case Study: Application of a FGIS Decision Support Tool to Urban Watershed Management in Fulton County, Georgia

The high density of development in Sandy Springs, a suburban area northwest of Atlanta, reduces the opportunities for new, areawide management practices such as regional detention ponds. Instead, multiple on-site or local management practices are recommended. In response to the need for developing storm water and water quality plans, a GIS application called LORELEI was developed (Slawecki et al., no date). LORELEI allows users to rapidly develop and compare watershed management alternatives for catchments with hundreds of management practices. It was developed to

- Keep track of hundreds of candidate management practice sites.
- Develop management scenarios using different combinations of management practices.
- Evaluate the practices' impact on water quality.
- Compare scenario results.
- Present the information to a wide range of people.

LORELEI provides decision support through data management, scenario development and evaluation, and enhanced involvement in and understanding of the watershed management process. LORELEI stores data about potential management practice locations and associated costs, practice types, and effectiveness data, as well as standard geographic information such as natural features, watershed delineations, and property ownership. Through scenario development, the program allows for rapid selection of individual projects and entire categories of management practices to build various scenarios. LORELEI then evaluates the scenarios to estimate and compare their costs and benefits. Finally, with enhanced involvement and understanding, LORELEI uses GIS to give decision makers an opportunity to participate directly in the watershed management process and to clearly understand issues, components, and cost and benefit implications of different management scenarios. GIS linkages allow for fine-tuning of the scenarios to determine the cost and performance effects of different suggestions made by participants at public meetings.

developed a conceptual process to guide their assessment and management. The process is divided into three phases: the scoping phase, the analysis phase, and the implementation and management phase. Within each phase are a group of interrelated steps that if followed, typically lead to a complete analysis of the cumulative effects on a watershed. The three phases and their steps are shown in Figure 3.1.

e. Estimate the effectiveness of treatment practices

A useful tool to estimate the effectiveness of treatment practices on water quality is the Watershed Treatment Model (WTM), which was developed by the Center for Watershed Protection (Caraco, 2001). The WTM is a simple model for rapidly assessing how various management programs influence pollutant loadings and/or habitat quality in urban watersheds. It incorporates many simplifying assumptions that allow watershed managers to assess various programs and sources that are not typically tracked in more complex models. The WTM consists of two basic components: pollutant sources and treatment options. The pollutant sources component estimates the load from a watershed without treatment measures in place. It assesses two broad categories of pollutant sources: primary land uses and secondary sources. The treatment options component estimates the reduction in the uncontrolled load resulting from a wide range of treatment measures. Treatment options are broadly defined in the model as storm water treatment practices and storm water management programs. The most current version of the WTM, version 3.0, can track sediment, nutrients, and bacteria. The WTM can be a useful tool for managers who are analyzing the effectiveness of current watershed restoration programs,

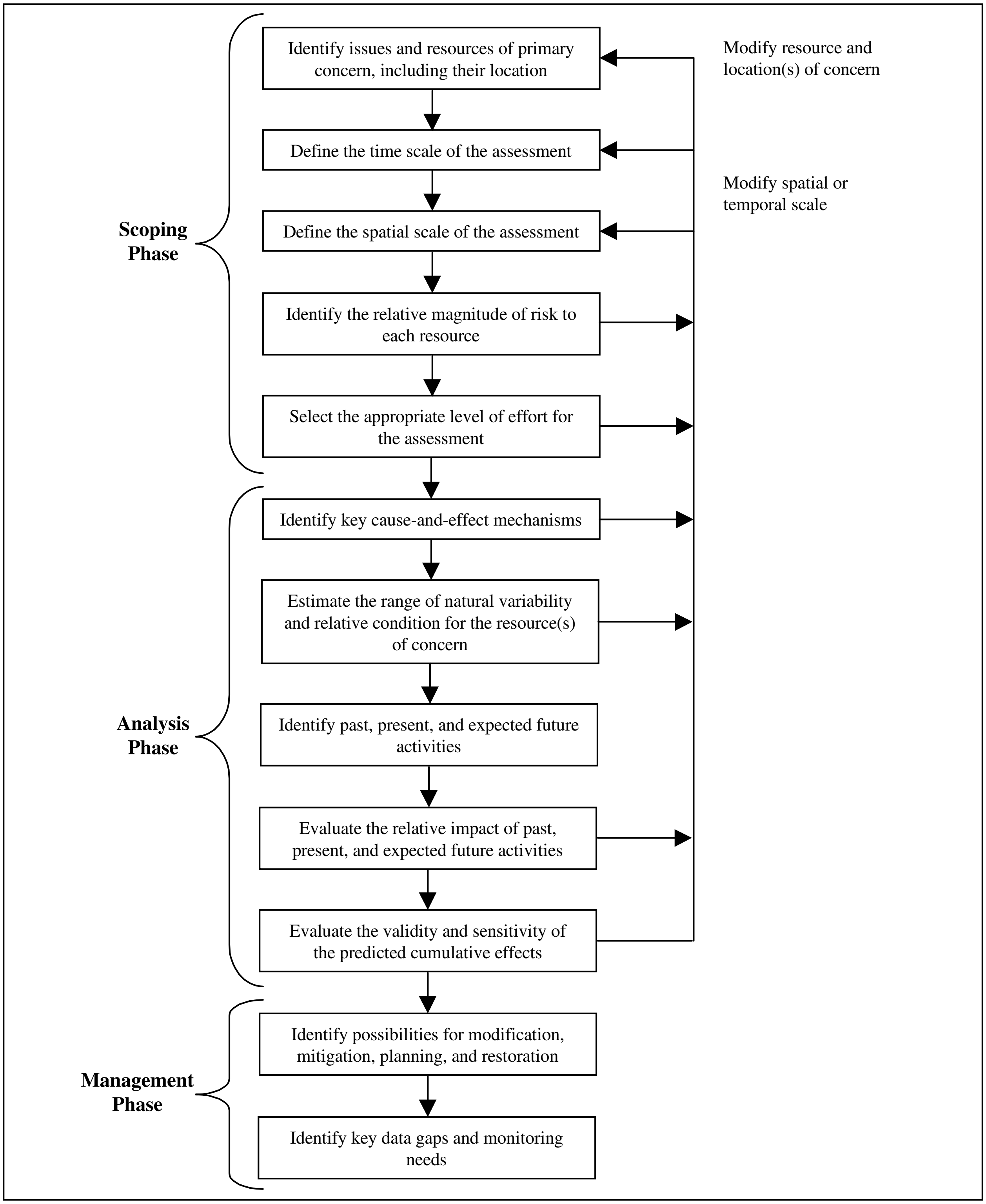

Figure 3.1: Conceptual process for assessing cumulative effects (MacDonald, 2000).

preparing Total Maximum Daily Loads (TMDLs), or evaluating the watershed benefit of National Pollutant Discharge Elimination System (NPDES) storm water programs. For more information about the WTM, contact the Center by e-mailing center@cwp.org or visit their web site at www.cwp.org.

2. Establish a Set of Watershed Indicators

Watershed indicators are monitoring parameters or techniques used to measure the effectiveness of management practices in meeting watershed and subwatershed goals and objectives. Indicators range from complex chemical or toxicity testing methods to simple public perception surveys. Watershed managers can choose one or more of these indicators to better focus their monitoring efforts. Regardless of the parameters or technique, to be effective, an indicator must

- Reflect a measurable attribute of a watershed goal or subwatershed management objective.
- Be measured using scientifically valid protocols, quality controls, and assessment techniques to ensure that results are replicable, consistent, compatible with other data collection efforts, and statistically valid.
- Be measured at one or more locations that will adequately characterize “typical” conditions in the management unit and establish reference conditions against which future data comparisons can be made.
- Be monitored over a long enough period of time to establish observable trends.
- Be compatible with available financial, personnel, and other resources.

The Center for Watershed Protection and EPA published an excellent reference to help municipalities select a suite of indicators that will most effectively measure conditions in their watershed (Claytor and Brown, 1996). This publication, *Environmental Indicators to Assess Stormwater Control Programs and Practices*, presents profiles with information such as advantages, disadvantages, cost, and applicability for 26 indicators, which include water quality, physical/hydrological, biological, social, programmatic, and site indicators. It can be ordered on-line at www.cwp.org.

a. Establish water quality indicators

Conduct water quality monitoring. This type of monitoring involves measuring pollutants in both runoff and base flow conditions. The most commonly measured constituents are oxygen demand, nutrients, metals, pH, temperature, flow, solids, fecal coliforms, and polycyclic aromatic hydrocarbons (PAHs). Measurements can be taken at management facilities or in receiving waters. This method allows for the identification of trends in water quality over time and can identify areas that are degraded relative to low-impact reference sites. Changes in water quality that result from changes in land use or from the implementation of management practices can be detected to prioritize future conservation or restoration efforts. The specific constituents found in receiving waters can aid in identifying the source of the pollution problem and help target management practices effectively. The methodology for water quality monitoring is well outlined in specific protocols, and results are quantitative and easy to present and compare to other monitoring databases. However, the monitoring effort must be long-term because of the high variability in constituent concentrations and might be expensive because of labor requirements or equipment costs for automation.

(1) *Conduct toxicity testing*. These methods, often called whole effluent toxicity (WET) tests, involve exposing standardized freshwater, marine, and estuarine vertebrates, invertebrates, and plants to water samples to directly measure the adverse effects of effluents. Both acute and short-term chronic effects can be assessed. The test organisms can be either resident species or species that will be restocked or reintroduced. Toxicity reduction evaluation (TRE) can be used to identify the agent of toxicity, which helps to identify the pollutant source and indicates which management practices would be appropriate to treat the problem. Although this method allows managers to distinguish between a range of conditions and chemicals, species' responses vary substantially with respect to the choice of species, location (laboratory or in situ), and duration of the test. Also, chronic toxic effects, which may take a long time to manifest, are not measured with this type of testing. The TRE process can be expensive and is often used to specifically identify pollutants when receiving waters have previously been identified as impaired through other, less expensive methods. More information on WET methods is available at *www.epa.gov/OST/WET*. Descriptions and guidance on other analytical methods are provided at *www.epa.gov/ost/methods* (USEPA, 2000d).

(2) *Measure the frequency at which water quality standards are exceeded.* This method is usually based on chemical standards and can be derived from existing data or as part of the biennial 305(b) reporting process. It can identify long-term trends in water quality, storm water impacts, and the effectiveness of management practices. However, because the ability to detect exceedances is highly dependent on the frequency and timing of sample collection, brief periods of exceedance might be missed (during storm flow) and long-term conditions inaccurately represented. Also, exceedance frequencies provide little information about causes and sources of pollution. Costs associated with this method are minimal because data are usually collected through other programs. Guidance and information on EPA and state water quality standards and criteria can be found at *www.epa.gov/ost/standards* (USEPA, 2001c).

(3) *Determine sediment pollutant levels*. This type of monitoring involves the determination of pollutant load carried by sediments and deposited in slow-moving receiving waters. Analysis is usually conducted using spectrophotometry and chromatographic tests of samples from natural or artificial waterbodies. The extent of toxicity in sediments can be determined by comparing sample results to reference samples that are known to be relatively unimpacted. Measured pollutant levels can also be compared to existing standards for typical contaminants in sediment (USEPA, 2000d). Using sediment contamination as an indicator of water quality is often confounded by uncertainty related to levels of concern and long-term impacts, the inability to identify pollutant sources, and lag time between discharge and settling. However, long-term trends in sediment pollutant loading can be detected if monitoring is conducted over a long period of time.

(4) *Measure microbial contamination.* This type of monitoring involves measuring concentrations of microbes such as fecal coliform or *Escherichia coli* to ascertain the probable presence of pathogens in the water column. These pathogens result in the closure of beaches and shellfish beds. Tracking the frequency of such closures might indicate that effluent from industrial or municipal facilities, septic systems or runoff from agricultural areas is contaminated. In areas where no treatment facilities or septic systems are present, runoff can be identified as the main source of pathogens. Measuring microbe concentrations can help determine the effectiveness of management practices in removing this type of contamination from receiving waters.

Trends in beach or shellfish closures over time might indicate a developing problem if they become more frequent or might demonstrate the effectiveness of management efforts if they decrease. However, many of the bacteria measured have a variety of nonhuman sources, making it difficult to identify the source of the pollution. In addition, they are short-lived in the water column, so depending on when samples are collected, the occurrence of high bacterial concentrations might not be detected even though they are present at some times (during storm flows). DNA testing is an expensive but effective method for identifying the primary animal (human, duck, dog, etc.) sources of microbes present in the water column. More information on DNA testing can be obtained by contacting Dr. Mansour Samadpour at the Department of Environmental Health, University of Washington, Box 357234, Seattle, Washington; telephone 206-543-5120; e-mail mansour@u.washington.edu (CWP, 1999).

(5) *Measure nonpoint source loadings.* It is possible to estimate the amount of pollutants transported in storm water runoff from various land uses by using empirical monitoring data, land use imperviousness and cover, area, and rainfall volume. Modeling of pollutant loads can establish baselines that can be used to determine whether changes have occurred as a result of land use changes or implementation of management practices. Loadings can be calculated for small-scale studies using the Simple Method as described in *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs* (Schueler, 1987). Alternatively, several computer simulation models are available to model changes in nonpoint source loads under different scenarios.

Another source of information for estimating pollutant releases is the Healthy Community Environmental Mapping program, called HUD E-MAPS (HUD and USEPA, 2000). HUD E-MAPS, which was developed by the Department of Housing and Urban Development (HUD) and EPA, combines EPA environmental data with information on HUD's community development and housing programs. The program provides location, type, and performance information on HUD-funded activities throughout the country and select EPA pollution release information. The maps help community planning by allowing communities to identify areas of pollutant releases when planning economic development and housing projects. The HUD E-MAPS program can be accessed at www.hud.gov/emaps.

Case Study: Maryland's Environmental Indicators

The state of Maryland has compiled several indicators to characterize environmental quality (MDE, 1999). These indicators embody a range of environmental attributes, from air quality to drinking water quality to public understanding and community support. The Non-Tidal Aquatic Systems category, which encompasses the range of plants and animals found in free-flowing rivers, streams, lakes, and most wetlands, includes several indicators that appropriately address Maryland's habitat and land uses and include physical, chemical, and biological measures:

– Miles of Streams Degraded by Abandoned Mine Drainage.
– Stream Miles Open to Migratory Fish.
– Physical Habitat Index (Non-Tidal).
– Benthic Macroinvertebrate Index of Biotic Integrity (Non-Tidal).
– Fish Index of Biotic Integrity (Non-Tidal).
– Riparian Forest Buffers.

The biological indicators consider communities of living organisms as found throughout the water column rather than any individual species, and their values reflect the physical and chemical water quality conditions described by other indicators. The Riparian Forest Buffers indicator was chosen because of its importance to physical and chemical habitat and its contribution in cycling nutrients to aquatic species and because a statewide benchmark had already been established through the Chesapeake Bay Program.

More information on Maryland's environmental indicators is available at *www.mde.state.md.us/enpa/2000_enpa/envi_indicators*.

b. Establish physical and hydrological indicators

EPA's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (USEPA, 1999) and *Volunteer Stream Monitoring: A Methods Manual* (USEPA, 1997c) provide guidance on how to conduct assessments of a waterbody's physical, habitat, and hydrological characteristics. Both documents are available on the Internet: the former can be found at *www.epa.gov/owow/monitoring/rbp*, and the latter is located at *www.epa.gov/owow/monitoring/volunteer/stream*.

EPA also provides guidance for lake and reservoir monitoring in *Lake and Reservoir Bioassessment and Biocriteria* (USEPA, 1998b), which is available at *www.epa.gov/owow/monitoring/tech/lakes.html*. Monitoring guidance for estuarine and coastal marine waters can be found in *Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Guidance* (USEPA, 2000a), located at *www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html*.

Additional monitoring guidance can also be obtained from EPA's Environmental Monitoring and Assessment Program (EMAP), a research program designed to develop the necessary tools for monitoring and assessing the nation's ecological resources. The objective of the program is to guide national monitoring initiatives and activities with improved scientific understanding of ecosystem integrity and dynamics. Information about the EMAP program is available at *www.epa.gov/emap*.

(1) *Measure stream widening/downcutting*. Measurements of stream width, depth, and bank characteristics taken over time can be used to indicate changes in the magnitude and frequency of storm flows caused by land use changes that affect stream geometry. Such measurements are also useful in identifying stream segments that are especially susceptible to

erosion and areas where habitat is degraded to target areas for implementation of management practices. Many stream channels are already modified, so baseline conditions need to be established. This method cannot be used to predict changes, but it can help to diagnose a problem after it has occurred. Booth (1994) presents excellent guidance for conducting measurements of stream cross-sectional area.

(2) *Conduct physical habitat monitoring*. Physical habitat monitoring is used to assess the potential of the stream to support different kinds of biota. Parameters such as weather, stream type and origin, land use, erosion, reach width and depth, canopy, proportion of stream morphological type (pool, riffle, and run), and presence or absence of large woody debris and aquatic vegetation can be measured easily and inexpensively and can provide information about which taxa would likely be found in the stream without water quality impacts (reference condition). If conducted over time, monitoring can provide information about past, present, and future changes in channel morphology. Although this method detects impacts from relatively low levels of development, it is not useful in pinpointing sources of degradation, nor does it offer insight into other water quality impacts.

(3) *Assess dry weather flows*. This method assesses the impact of urbanization on base flows, either as compared to a nonurbanized stream in the same ecoregion or as a change over time. Impacted streams in humid areas show decreased flow, whereas perennial streams in arid regions show increased flows as a result of urbanization. Evaluating pipe installations and impervious surfaces in humid regions and water use in arid regions allows this method to identify causes of base flow alteration. This method works well in conjunction with stream widening/downcutting studies. It does not distinguish between urbanization and other causes of stream flow alteration such as irrigation, long-term drought, and the like, unless these factors are taken into account explicitly. Also, it is difficult to establish trends without extensive long-term data and knowledge about certain geologic conditions.

(4) *Measure flooding*. It is important to quantify changes in stream morphology over time because alterations in stream size, shape, or floodplain boundaries indicate that hydrologic changes have resulted from development in the watershed. These changes can be identified by comparing historical floodplain records to current floodplain maps. These maps, called Flood Hazard Boundary Maps (FHBMs), are official maps issued by a community administrator that detail the boundaries of the flood, mudslide, and related erosion areas having special hazards that have been designated (FEMA, 2000). The maps can be obtained from local community map repository sites, from the Federal Emergency Management Agency (FEMA) on-line at www.fema.gov/MSC/product.htm, or through FEMA by phone, fax, or mail from the Map Service Center, P.O. Box 1038, Jessup, Maryland 20794-1038; telephone 800-358-9616; fax 800-358-9620.

(5) *Monitor stream temperature*. This method identifies areas where stream temperature has increased as a result of urbanization and loss of shading and buffers. Stream temperature can be measured over time or compared to other, low-impact watersheds. This monitoring method identifies areas that would potentially benefit from riparian buffer enhancement and measures the effectiveness of management practices used to regulate stream temperature. Changes in stream temperature can be an early warning sign that sensitive species will be lost without intervention. Climatic conditions can cause variability in stream temperature that is

extraneous to trends caused by urbanization and can confound analyses. Also, some management practices, such as ponds and wetlands, can result in increased temperature.

Case Study: Development and Evaluation of Ecosystem Indicators for Urbanizing Midwestern Watersheds

Researchers at Purdue University are undertaking a study to develop predictive indicators of urbanization that are applicable to midwestern watersheds (Spacie et al., 2000). The objectives of this study are as follows:

- Quantify impacts on hydrologic regimes, water quality, and habitat structure of stream ecosystems using paired experimental watersheds.
- Develop linked models to accurately predict these impacts.
- Use the models to generate and test indicators of urbanization and hydrologic change with respect to biological responses to these changes.
- Use these indicators with the models to assess biological responses to alternative urbanization scenarios on larger scales.

Data from satellite imagery, intensive water quality and biological sampling, stream cross-section measurements, and physical habitat assessments will be used to develop and test the models. A dynamic hydrology model that can simulate cross-sectional averaged velocities, shear stress velocities, and water depth variability during storm peaks has been developed. Functional biological metrics and habitat quality indices will be correlated not only to land use but also to channel morphometry and flow variability.

c. Establish biological indicators

Bioassessments are useful for detecting aquatic life impairments and identifying the causative agent and possible mitigation strategies. Additional bioassessments can indicate whether mitigation was successful and can direct further management activities. Monitoring of biological communities offers the following advantages:

- Biological communities reflect overall ecological integrity and directly relate to the primary goal of the Clean Water Act.
- Biological communities integrate the effects of different stressors and provide a broad measure of their aggregate impact.
- Biological communities provide an ecological measure of changes in environmental conditions.
- Routine biological monitoring is inexpensive relative to chemical monitoring and toxicity tests.
- Biological monitoring is useful for evaluating impairment when criteria for specific ambient impacts do not exist.

Bioassessments can include evaluation of fish populations, benthic macroinvertebrate communities, periphyton, and single species monitoring. EPA's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (USEPA, 1999) discusses the advantages of monitoring each community type and presents several methods that can be used for each. Additionally, EPA (2000b) published the *Stressor Identification Guidance Document*, which outlines a process to identify causes of biological impairment. The stressor identification process is outlined in Figure 3.2 and includes 3 major steps: (1) listing candidate causes of impairment, (2) analyzing new and existing data to generate evidence for each candidate cause, and (3) producing a causal characterization with the evidence generated in step 2 to draw conclusions about the stressors most likely to have caused the impairment. *Stressor Identification Guidance Document* is available for download in PDF format at *www.epa.gov/waterscience/biocriteria/stressors/stressorid.html* or can be ordered through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

The Biological Assessment of Wetlands Workgroup (BAWWG) (USEPA, 2001b) will provide information for establishing monitoring protocols for wetlands through its series of "state of the science" reports. These reports, which will be available in the spring of 2001, will include

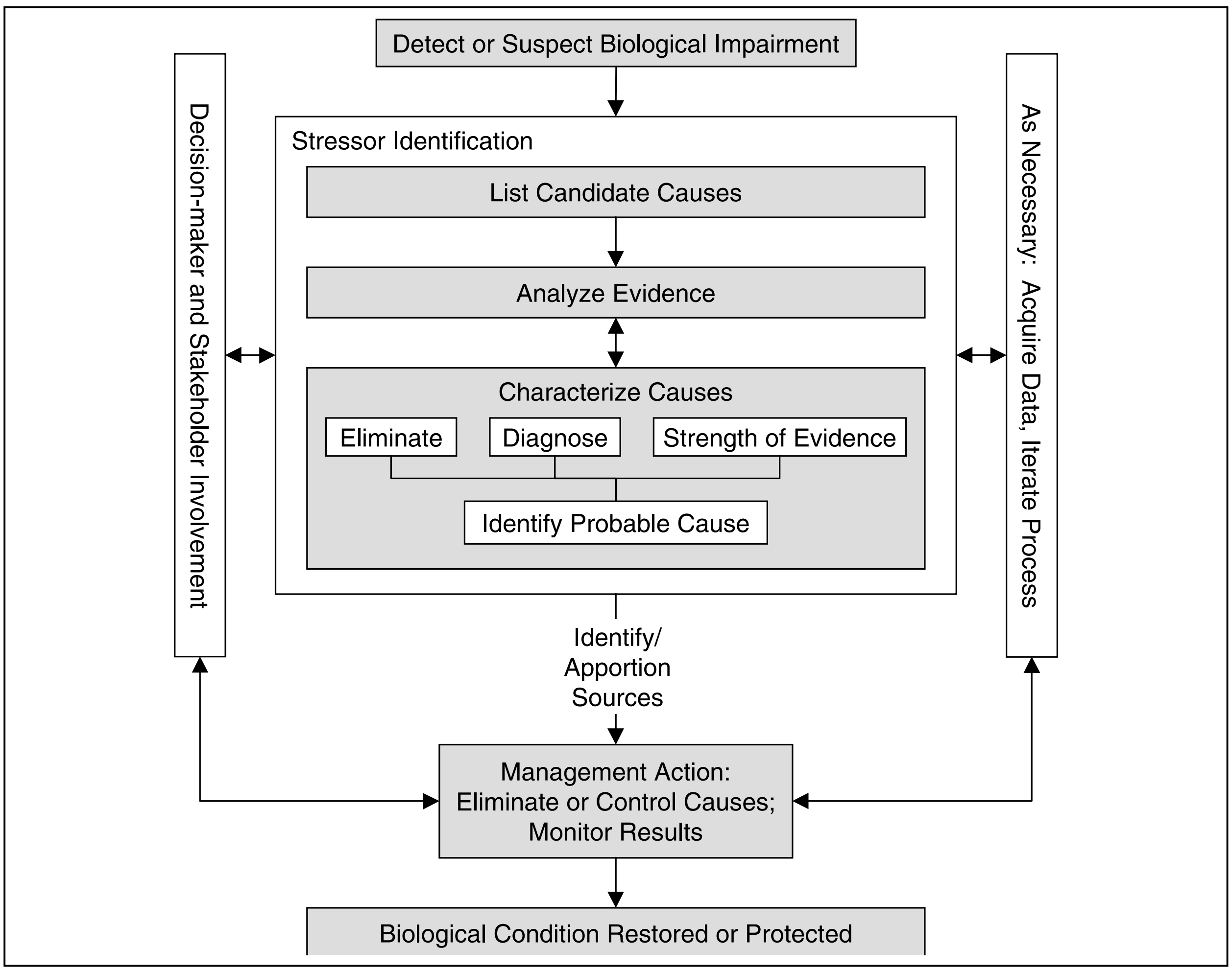

Figure 3.2: Conceptual diagram of the stressor identification process (USEPA, 2000b).

introductory modules on wetland bioassessments and modules on specific methods, such as bioassessment methods for macroinvertebrates. Although the reports will not provide specific prescriptive guidance, they will summarize current knowledge and provide options and recommendations to states for developing wetland bioassessment methods and programs. The modules will also point out limitations of current methods and identify research needs. Information from BAWWG is available at *www.epa.gov/owow/wetlands/bawwg/index.html*.

(1) *Assess periphyton populations*. Changes in periphyton or plankton community structure and distribution patterns can indicate a water quality problem stemming from thermal pollution, toxic chemicals, nutrients, and sedimentation. Because periphyton have a short life cycle, they are especially good indicators of short-term impacts. Measurements of chlorophyll, a chemical common to all periphyton, can also be used as an indicator of eutrophication. Although there are several levels of sampling and analysis of periphyton populations, rapid sampling can be relatively easy and inexpensive and has little impact on the ecosystem. Also, standardized methods (biomass, chlorophyll) can be used to analyze and interpret algal communities without doing an extensive taxonomic evaluation, which requires specialized training. One problem with these indicators is that plankton varies seasonally and is highly transient, making it a poor indicator of site-specific conditions.

(2) *Assess macroinvertebrate assemblages*. Macroinvertebrates are relatively immobile and are good indicators of site-specific effects. They have a short life cycle and therefore are good indicators of short-term stress. Measurements of invertebrate populations are usually compared to populations from a reference condition to determine the severity of pollutant impacts. The presence or absence of particular species can be used to infer poor aquatic integrity because macroinvertebrate assemblages typically cover a broad range of trophic levels and pollution tolerances that allow interpretation of multiple effects. Macroinvertebrate sampling has some drawbacks, including the fact that populations are highly habitat-dependent and vary with season, streamflow, and region, which can confound results. In addition, taxa identification requires training and can be complex and time-consuming. Despite these drawbacks, volunteer monitoring programs can be used to collect macroinvertebrate data. Both *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (USEPA, 1999) and *Volunteer Stream Monitoring: A Methods Manual* (USEPA, 1997c) provide guidance on how to conduct benthic macroinvertebrate assessments.

(3) *Assess fish assemblages*. This method includes measurements of fish diversity, species richness, species pollutant tolerance, disease prevalence, and a variety of other metrics that can be used to identify the nature and extent of a pollution or habitat problem. Measurements are taken in several different habitats within the stream and are usually compared to a regional reference condition to determine the extent of impairment. This method can also be used to evaluate the success of management practices. Because fish have a relatively long lifespan, they often react to chronic levels of pollutants and long-term impacts. Fish are also easy to collect and identify. However, fish populations are influenced by many other variables, such as stream size, region, season, temperature, and flow conditions, that need to be taken into account when analyzing the data. Also, fish that migrate might be affected by conditions in another area, not the area of interest. It is sometimes difficult to identify the source of problems in fish populations because of the prevalence of confounding factors that make interpretation of results difficult.

(4) *Assess single species indicators*. Trout, salmon, and freshwater mussels are often used for this type of assessment. Some species are popular with the public, and their popularity can help in rallying support for better management. Measuring only one species is relatively easy and inexpensive and might provide early diagnosis of degradation, which can facilitate remediation efforts. However, natural population fluctuations in a single species might skew results, and without corroborating evidence there is no way to prove conclusively that degradation has occurred. Also, focusing on protecting resources necessary for a single species might result in ignoring the management needs of other sensitive species.

(5) *Measure composite indicators*. This method typically involves developing an index that incorporates the results of several different bioindicators. Several metrics can be combined into a single integrity index, such as the number of native fish species or the number of intolerant macroinvertebrate taxa. Composite indicators provide a more comprehensive evaluation of storm water impacts than fish, macroinvertebrate, or single species indicators alone. Both long-term and short-term effects can be evaluated by using this type of metric. As with the other biological methods, populations are dependent on region, season, and flow. Reference site measurements are essential for valid comparisons when determining the extent of storm water impacts. Other measurements might be needed to identify sources of degradation.

d. Establish programmatic indicators

It is important to assess the effectiveness of a runoff management program. Claytor and Brown (1996) present several programmatic indicators that can be used to estimate the success of a management program and can help to direct future efforts. These include

- Number of illicit connections identified or corrected.
- Number of management practices installed, inspected, and maintained.
- Permitting and compliance.
- Growth and development.

Management Measure 12 discusses other ways to determine the effectiveness of runoff management programs.

e. Develop a suite of social indicators

Watershed managers can use several methods to gauge public perception of water quality issues and nonpoint source programs. These “social indicators” include

- Public attitude surveys.
- Industrial/commercial pollution prevention.
- Public involvement and monitoring.
- User perception.

More information about these indicators can be found in *Environmental Indicators to Assess Stormwater Control Programs and Practices* (Claytor and Brown, 1996).

Information Resources

The Caltrans *Guidance Manual: Storm Water Monitoring Protocols* (Caltrans, 2000a) provides step-by-step descriptions of the processes used to plan and implement a successful water quality monitoring program specific to runoff from transportation-related facilities. While the guidance manual emphasizes uniform policies and procedures for monitoring, the *Statewide Storm Water Management Plan* (Caltrans, 2000b) describes minimum procedures and practices Caltrans uses to reduce pollutants discharged from storm water drainage systems. These documents, along with other storm-water-related documents, can be downloaded in PDF format *www.dot.ca.gov/hq/env/stormwater/special/index.htm*.

Donigan and Huber (1991), in *Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas*, reviewed nonpoint source assessment procedures and modeling techniques for both urban and non-urban land areas. Detailed reviews of specific methodologies and models are presented, along with overview discussions focusing on both urban and non-urban methods and models. Brief case studies of ongoing and recently completed modeling efforts are described and recommendations for nonpoint runoff quality modeling are presented. This document can be downloaded in PDF format at *www.epa.gov/ost/basins1_data_files/docs/npsmodel.pdf* or ordered from the National Technical Information Service at *www.ntis.gov* or by calling 800-553-6847.

Patten et al. (2000) have undertaken a study to develop improved indicators and innovative techniques for assessing and monitoring ecological integrity at the watershed level in the western United States. Their objectives are to develop practical, scientifically valid indicators that span multiple resource categories, are relatively scale independent, address different levels of biological organization, can be rapidly and cost effectively monitored by remote sensing, and are sensitive to a broad range of anthropogenic and natural environmental stressors. More information about this project can be found at *es.epa.gov/ncer_abstracts/grants/99/ecological/patten.html* (NCER, 2001).

Compendium of Tools for Watershed Assessment and TMDL Development (USEPA, 1997a) supports the watershed approach by summarizing available techniques and models that assess and predict physical, chemical, and biological conditions in waterbodies. The publication discusses three major categories of models: watershed loading, receiving water, and ecological. Watershed loading models simulate the generation and movement of pollutants from the source to discharge into receiving waters. Receiving water models simulate the movement and transformation of pollutants through lakes, streams, and rivers. Ecological models simulate plant and animal communities and their response to pollutants and habitat modification. This document is available through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

EPA's *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA, 1997b) gives an overview of nonpoint source pollution and covers the development of a monitoring plan, data analysis, quality assurance/quality control, and biological monitoring. The manual addresses the design of water quality monitoring programs to assess both impacts from nonpoint source pollution and the effectiveness of control practices and management measures. It is available through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

Volunteer Stream Monitoring (USEPA, 1997c) serves as a tool for program managers who want to launch a new stream monitoring program or enhance an existing program. It presents methods that have been adapted from those used successfully by existing volunteer programs. The guidance is available in HTML and PDF formats at *www.epa.gov/owow/monitoring/volunteer/stream*.

The *Lake and Reservoir Bioassessment and Biocriteria* (USEPA, 1998b) guidance was developed through the experience of existing state, regional, and national lake monitoring programs and is oriented toward practical decision-making rather than research. Its primary target audiences are state and tribal natural resource agencies. It is intended to provide managers and field biologists with functional methods and approaches that will facilitate the implementation of viable lake bioassessment and biocriteria programs that meet their needs and resources. The document can be obtained in HTML format at *www.epa.gov/owow/monitoring/tech/lakes.html*.

Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish (USEPA, 1999) is a practical technical reference for conducting cost-effective biological assessments of lotic systems. This guidance is intended to provide basic, cost-effective biological methods for states, tribes, and local agencies that (1) have no established bioassessment procedures, (2) are looking for alternative methodologies, or (3) may need to supplement their existing programs (not supersede other bioassessment approaches that have already been successfully implemented). The scope of this guidance is considered applicable to a range of planning and management purposes, i.e., they may be appropriate for priority setting, point and nonpoint-source evaluations, use attainability analyses, and trend monitoring, as well as initial screening. The guidance is available in HTML and PDF formats at *www.epa.gov/owow/monitoring/rbp*.

The *Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Guidance* (USEPA, 2000a) provides an extensive collection of methods and protocols for conducting bioassessments in estuarine and coastal marine waters and the procedures for deriving biocriteria from the results. Several case studies illustrate the bioassessment process and biocriteria derivation procedures. This document can be downloaded in PDF format at *www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html*.

The *Stressor Identification Guidance Document* (USEPA, 2000b) leads water resource managers through the process of stressor identification and evidence assembly. The guidance can be used whenever biological impairment is present in an aquatic ecosystem and the cause is unknown. The stressor identification process combines multiple methods to determine the causes of impairment, and the methods are presented in order by the kinds of evidence used, from site-specific to more general information. The *Stressor Identification Guidance Document* is available in PDF format at *www.epa.gov/waterscience/biocriteria/stressors/stressorid.html*.

Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban (USEPA, 2000c) helps local officials to focus limited resources by establishing statistical sampling to assess, inspect, or evaluate a representative set of management practices, erosion and sediment controls, and onsite wastewater treatment systems. The document can be downloaded in PDF format at *www.epa.gov/owow/nps/urban.pdf*, or it can be ordered through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

EPA's web site, *An Introduction to Water Quality Monitoring,* contains a wide variety of resources for those interested in learning more about water quality monitoring, automated data management, and geographic information systems (USEPA, 2001). Many EPA guidance documents, fact sheets, and final reports are available from this site, which can be accessed at *www.epa.gov/owow/monitoring/monitor.html*.

EPA's web site, *Water Quality Criteria and Standards Plan* (USEPA, 1998d), describes six new criteria and standards program initiatives that EPA and the States and Tribes will take over during the next decade. The Plan presents a "vision" and strategy for meeting these important new initiatives and improvements and will guide EPA, states, and tribes in developing and implementing criteria and standards that provide a basis for enhancements to the TMDL program, NPDES permitting, nonpoint source control, wetlands protection, and other water resource management efforts. The web site is located at *www.epa.gov/ost/standards/quality.html*.

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